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Design, Testing and Improving Performance of a Silicon Pixel-Based Telescope

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New Perspectives
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1. The University of Chicago
2. Argonne National Laboratory

Future of LHC:

- 10 times the luminosity
- ITK upgrade
- Testing of modules (inner tracker)

How do we test them?

- Test beam experiments
- A telescope provides reference tracks for reconstruction

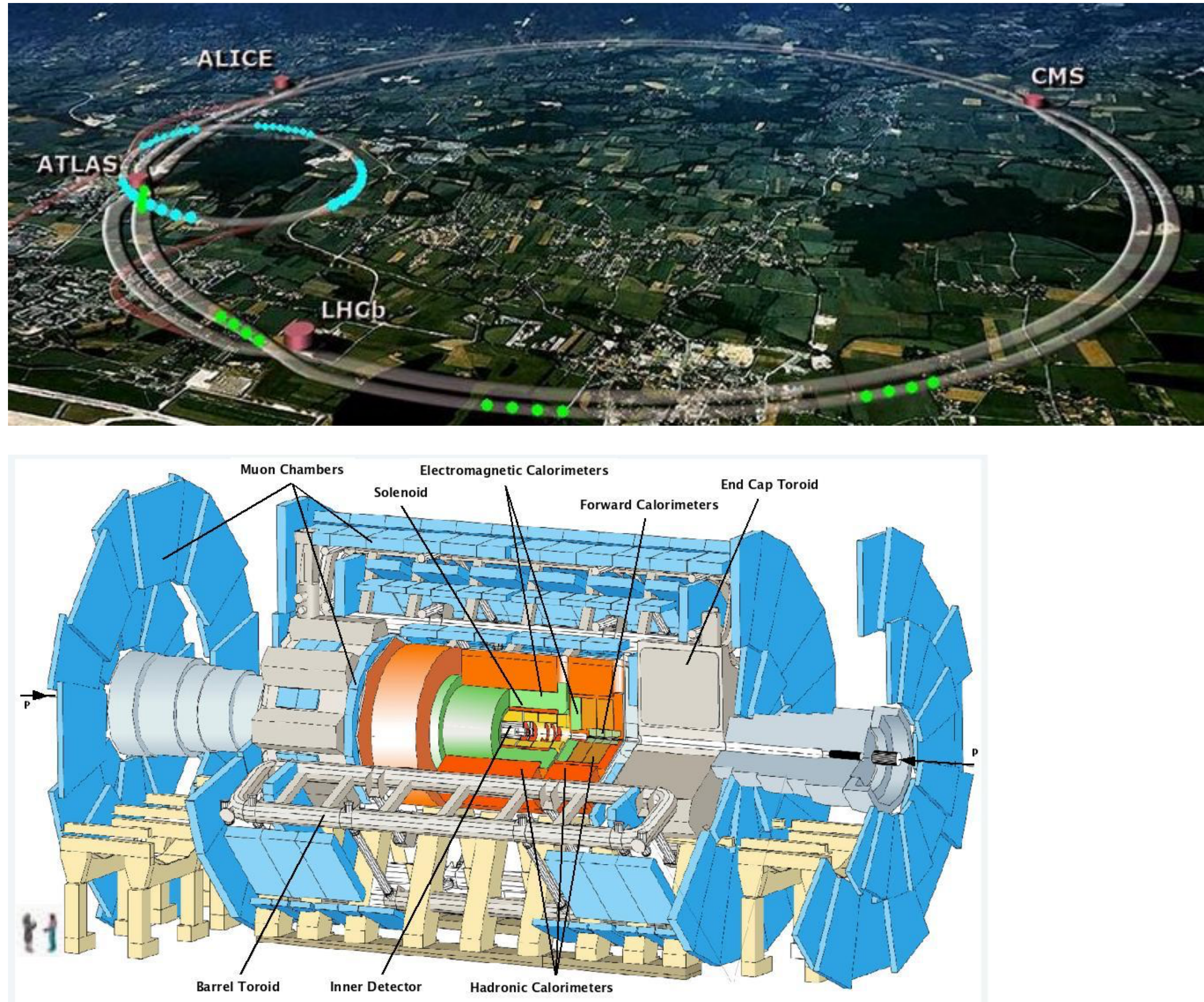

Fig.1. (top) The particle accelerator ring at CERN (bottom) The ATLAS detector at the LHC in CERN.

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Our goal is to design and test a telescope for characterization of small-scale prototypes for the ATLAS upgrade

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In MT6.1B Enclosure

Fig. 2. Telescope at the MT6 Test Beam Facility at Fermilab. It consists of six planar silicon pixel detectors with the Device Under Test (DUT) in between.

Picture by Dr. Vallary Bhopatkar

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- Each plane has four hybrid silicon sensors
  - Pixel size: 250×50 μm^2
  - Pixel array: 80×336, col×row
- Each sensor is attached to a FE-I4 chip using bump-bonding technique.
  - We only use one of the four chips during data-taking.

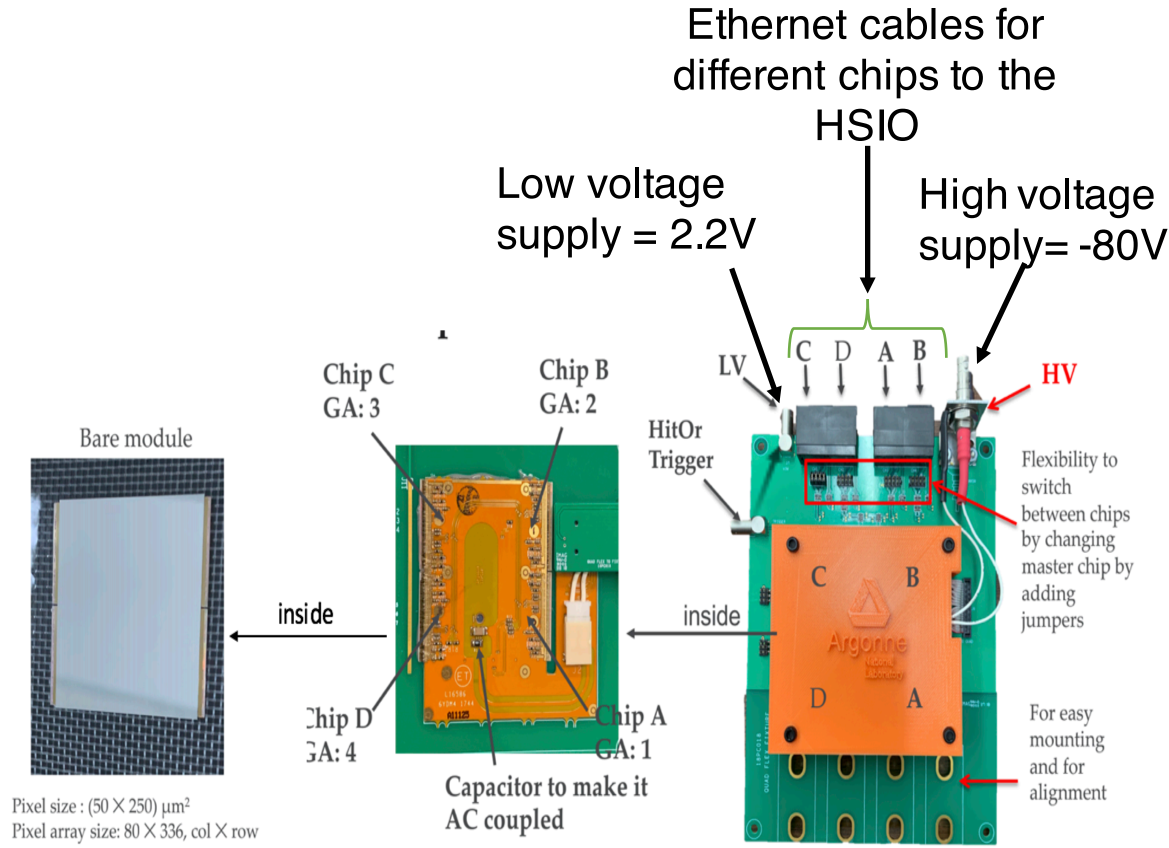

Fig.3. Picture showing the insides of a detector plane. Picture by Dr. Vallary Bhopatkar

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- Triggering and data-collecting happens in the HSIO (High Speed I/O) board
  - RCEs (Reconfigurable Cluster Elements) used to store and transmit data from individual telescope planes (18 I/O channels to read data from each plane separately)
- CalibGui/CosmicGui is the RCE software used for data acquisition
- Trigger planes connected to HSIO
  - Currently triggering on two planes (first and last)

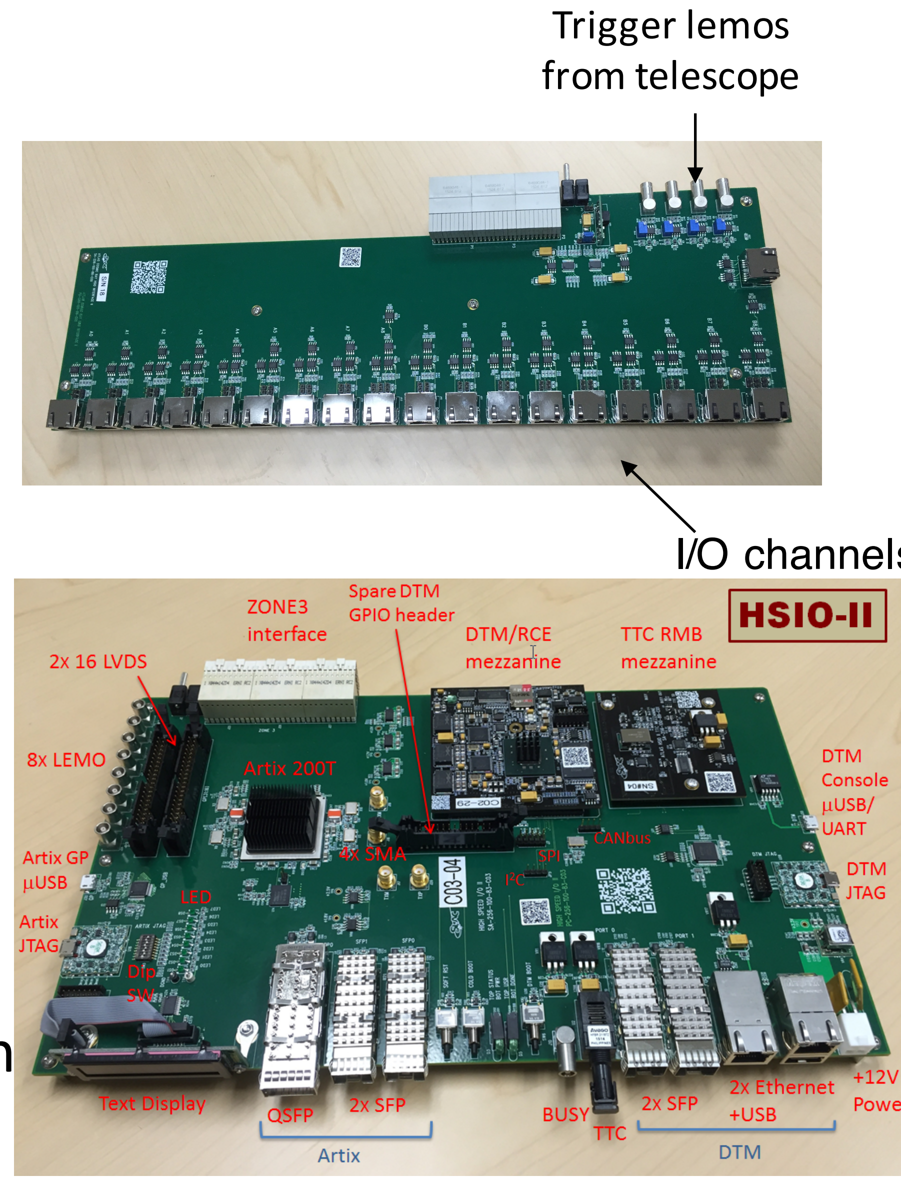

Fig. 4. Picture showing the HSIO board (bottom) and its connections (top) [2]

Telescope characterization

- Most chips were not functional at room temperature
- Possible causes include:
    - Poorly manufactured chips i.e. issues with bump bonding
    - Noisy pixels found in the sensors
    - High leakage current ~ 10 μA instead of 2 μA

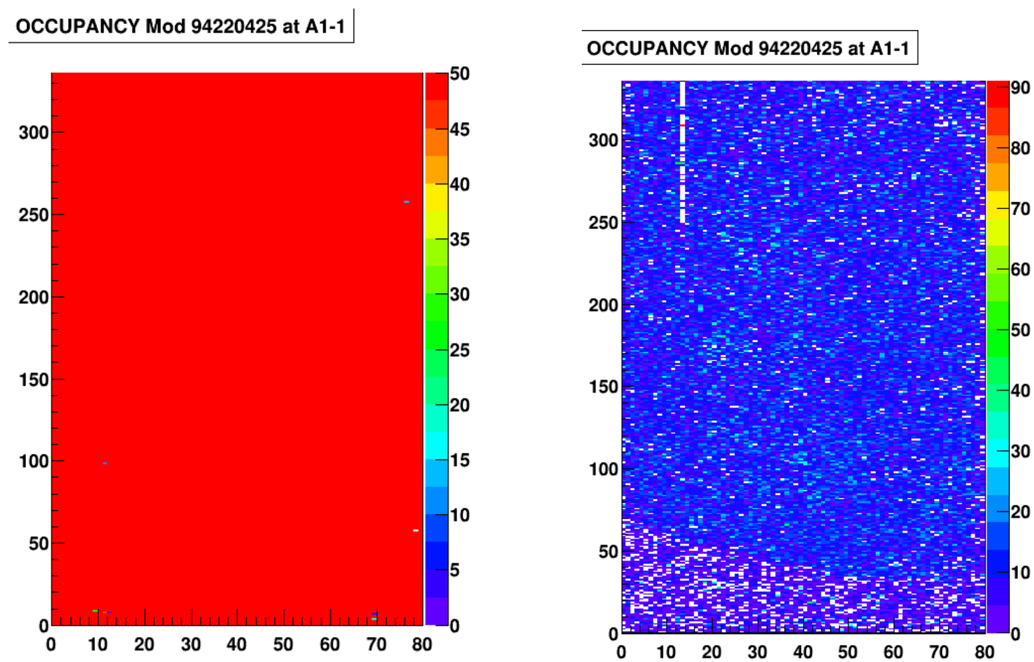

Fig. 5. Occupancy plots of a good chip (left) and a bad chip (right). Made in CalibGui.

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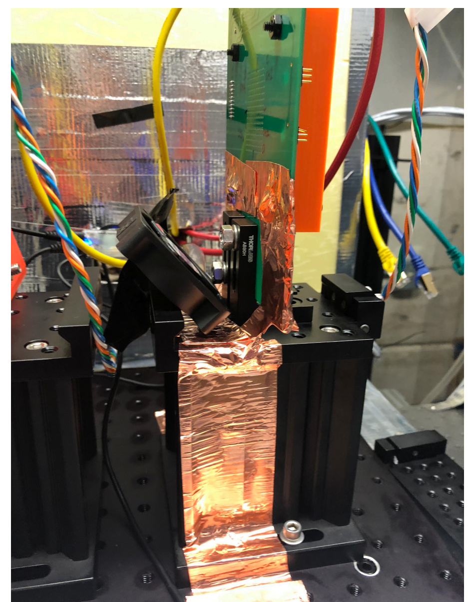
Results after cooling

- Three telescope planes were recovered after cooling the chips to 12°C
- Planes cooled in a thermal enclosure using the JULABO chiller
- Temperature monitored over time remotely
- Nitrogen/dry air was pumped into the enclosure to manage humidity

Argonne setup



Fermilab setup

Fig. 6. (top) Telescope plane placed in the chiller during testing. (bottom) Telescope plane in the test beam cooled further by copper tape and a fan

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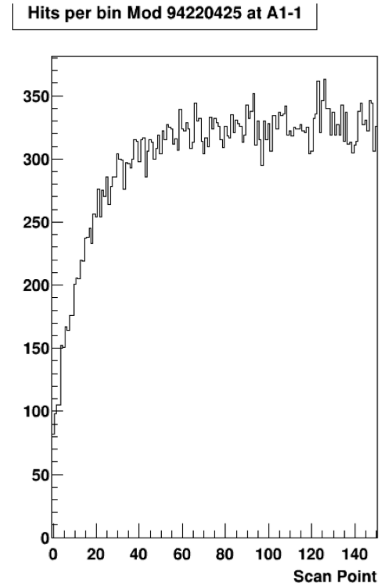
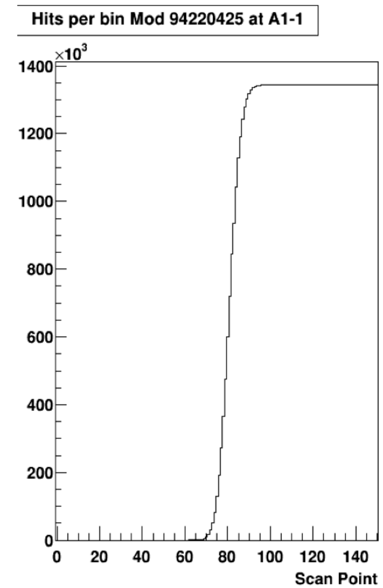
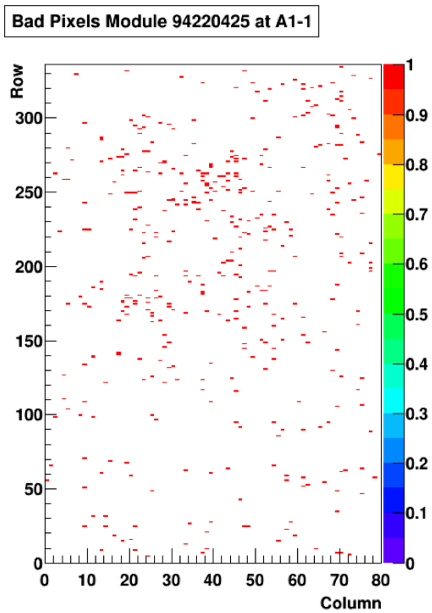


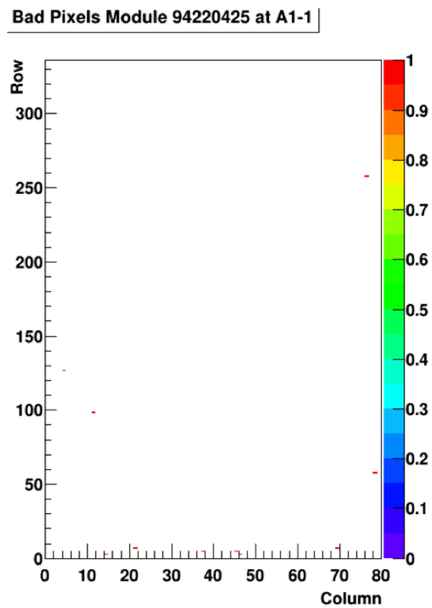
Before cooling



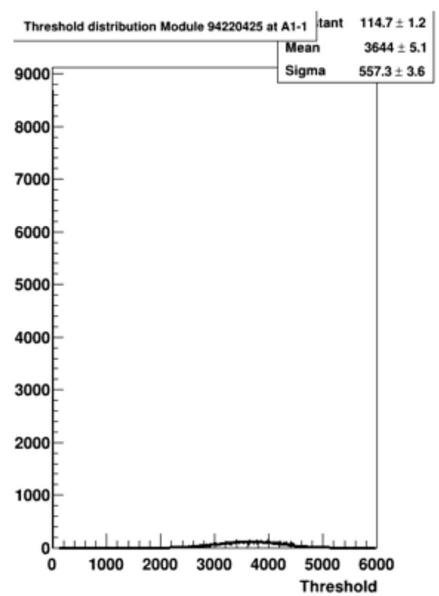
After cooling



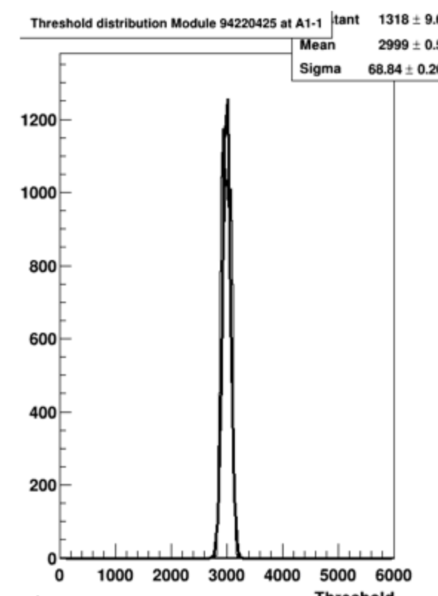
Before cooling



After cooling



Before cooling



After cooling

Fig. 7. Plots from a threshold scan before (left) and after (right) cooling. Top left: Bad pixels 2D plot. Top right: Hits per bin vs. scan point. Bottom: Threshold distribution 1D plot. All plots made in CalibGui.

Spatial resolution of the telescope

Simulation results:

- Simulation of the spatial resolution of the telescope using Allpix^2,a Geant4-based software developed by CERN
- Current pixel size is on the order of $250 \times 50\ \mu$m.
- Pixel size determines the resolution i.e smaller pixel size->better resolution
- Efforts to reduce pixel size by tilting the planes

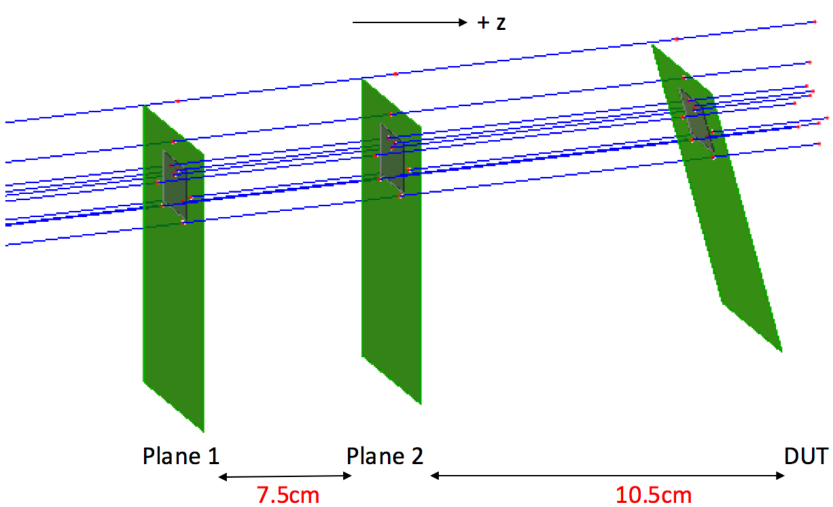


Fig. 8. Simulation of the telescope planes using Allpix^2. Blue lines are reconstructed beam tracks. DUT is tilted by 15 degrees about the X axis. [1]

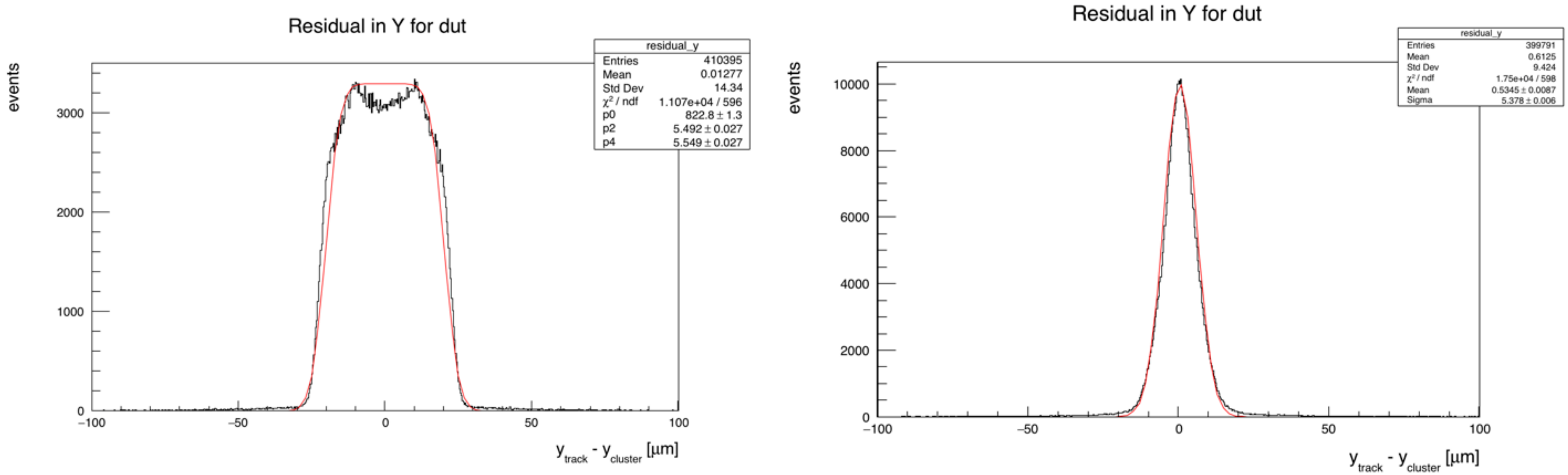
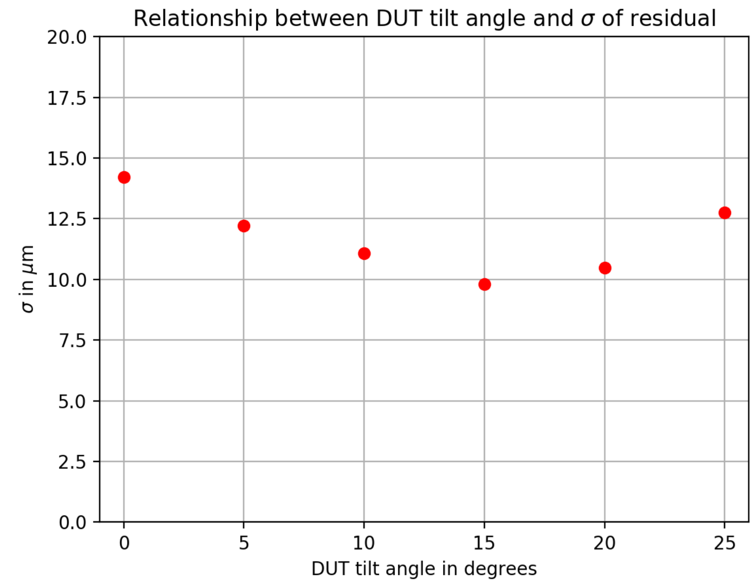


Fig. 10. Simulated Y residual plot for vertical plane (left) and a plane that is tilted by 15 degrees about the X axis. Made using Allpix^2. [1]

- Residual: distance between the coordinates of the actual pixel hit(in this case, it is the cluster position which is determined by the center-of-gravity position of the pixels in the cluster) and that of the reconstructed track
- Width of the distribution determined by the spatial resolution
- Theoretical width is given by: $\sigma = \frac{Pixel\,pitch}{\sqrt{12}}$

- Spatial resolution depends on clustering of pixels, mainly the cluster size i.e. number of pixels per cluster
- Cluster size depends on tilt angle, it increases with tilt angle
- Optimal cluster size for tracking is between 1 and 2 pixels per cluster i.e. 15 degrees



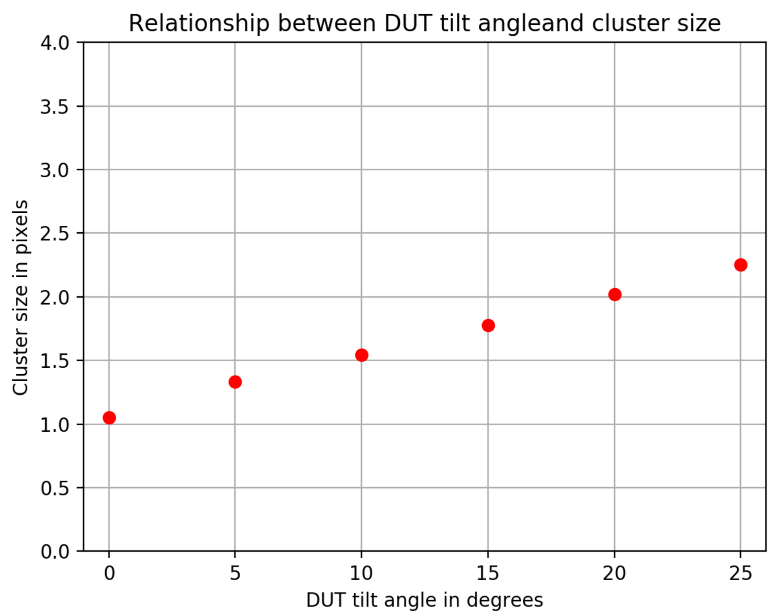


Fig. 9. Top: Simulated plot of resolution (um) versus tilt angle (degrees)
Bottom: Simulated plot of cluster size vs. tilt angle

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Summary and future work

- The ANL telescope can lead to detector characterization for the ATLAS upgrade
- Testing of the silicon pixel detectors showed malfunction at room temperatures. However, they showed better performance upon cooling to lower temperatures
- Pixel size of the telescope is on the order of 250×50 μm. It can be improved by tilting the telescope
- Future work involves taking data with the test beam and comparing the spatial resolution to the simulated results

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